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# History and potential of renewable energy development in New Zealand

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ABSTRACT

Many years before greenhouse gas emission reduction became a major driver for renewable energy development, New Zealand was an early adopter of several alternative energy technologies, particularly hydroelectricity and geothermal energy. It has achieved a level of 60% of total electricity generation from such sources, and is now pursuing a target of 95% of electricity generation from renewable energy, to be achieved in fifteen years. In recent years, however, the development of renewables has lagged that of other countries, particularly in fields such as wind power. The paper reviews the history, current status and potential of the major renewable energy technologies in New Zealand, and suggests what may be current barriers to development. It is seen that the likely major contributors to replacing fossil fuel based energy are likely to be wind power and expanded geothermal energy use, with biomass, marine and solar energy sources likely to play a lesser role. The barriers to development include environmental issues, the opportunity cost of biomass feedstocks, and a policy environment offering less incentive to RE development than is the case in many other countries.



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## 1. Introduction

Renewable energy (RE) utilisation has seen major global growth over recent years, driven by factors including emission reduction, security of energy supply, and employment—within a constraint of acceptable economic cost. In recent years the potential for greenhouse gas reduction has become the principal driver.

New Zealand is a country which was among the first to exploit several major forms of renewable energy. Among OECD countries it has the third highest contribution to primary energy supply (at five times the OECD average) and the third highest contribution of RE to electricity production. Yet development of RE in recent years, particularly in areas such as wind power, has lagged that of many other countries, with the percentage of RE actually reducing over the twenty years from 1990 [1]. The discussion which follows reviews development of RE in New Zealand, and suggests a number of factors leading to this situation.

## 2. Background

NZ is a small country of two main islands, together around one tenth larger in area than the UK, but with only one fifteenth of its population [2]. Much is sparsely populated, some 70% of the population living in only 16 major population centres, with the North Island having over three quarters of the population [3,4]. Its major natural resource is productive farmland, with pasture nearly 40% of total land cover [73]. Other natural resources, with the exception of hydroelectricity and coal are modest. Proven oil resources for example are minimal, and natural gas resources less than six years' consumption [5]. Relatively large coal reserves exist, with total in-ground resources estimated at 15 billion tonnes. Of this, however, around 12 billion tonnes is in the form of lignite. Much of the coal mined is exported, largely for blending with other coals for steelmaking and other purposes. Domestic consumption of coal is relatively low, at around 8% of total primary energy supply in 2009 [67].

Historically the principal energy source in NZ has been hydroelectricity, with most power generation in the South Island, and most consumption growth in the North Island. Other sources, particularly geothermal, have increased their contribution over recent decades. That is expected to continue, driven in part by a government objective to achieve 90% of electricity generation from renewable sources by 2025 [68]. The main sources of renewable energy are hydroelectricity, wind power, solar, and biomass. Geothermal energy as discussed in Section 5.4 is treated here as renewable energy, although as will be shown that is not strictly the case. The discussion which follows considers each of these in turn, in terms of their history and current supply, their future potential, and possible barriers to development.

## 3. Hydroelectricity

The use of hydro power has a particular place in NZ history, with the gold mining town of Reefton becoming in 1888 the first town in the Southern Hemisphere to have electric public lighting, with that supplied by a hydroelectric unit [6]. The NZ topography and climate favoured the exploitation of hydroelectric power, with two factors emerging early—the exercise of State control over such water use, and an emphasis on large schemes [7]. Hydroelectricity became the principal source of power, eventually comprising around 60% of total electricity supply [8]. The hydro industry has enabled the maintenance of some of the lowest power tariffs in the world [9]. Most hydro capacity was installed between the mid 1940s and late 1980s (see Fig. 1).

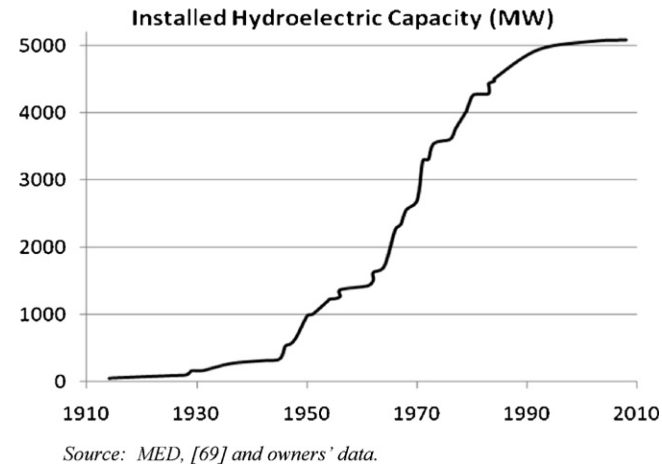



**Fig. 1.** Hydroelectricity capacity growth.

### 3.1. Potential hydroelectric capacity

While installed capacity effectively reached a plateau in 1990, potential remains for further development, albeit with significant barriers as discussed in Section 3.2. Studies on potential capacity have differed in their conclusions, reflecting the assumptions made as to constraints, both environmental and economic. A 2004 study [10] for example suggested that "the publicly known hydro potential for New Zealand is around 2500 MW and 12,000 GWh p.a."—implying an increase of around 50% on current capacity. Consultants Parsons Brinkerhoff in a 2005 report for the Electricity Commission identified around one hundred possible new schemes between 20 MW and 900 MW capacity. After excluding schemes not considered practical, they identified 34 schemes totalling 3536 MW [11]. In a later (2008) report, the list of potential developments was further reduced taking into account potential scheme size, cost-effectiveness and likely environmental consents, to a short list of eight schemes amounting to 1295 MW, at base costs ranging from $NZ78.7/MWh to $NZ126/MWh [14]. Notably in their earlier report they had also identified nearly 300 small potential schemes, ranging from 2 MW to 40 MW. The Parliamentary Commmissioner for the Environment [12] noted that most remaining big rivers were in conservation areas—but also that many smaller schemes might well be amenable to development.

Thus while potential exists for further hydro exploitation in NZ, future capacity growth is likely to be of a more modest scale than that of the past, although technical potential exists for some large run-of-river schemes [13]. Much growth is likely to be in smaller units, and strongly influenced not only by environmental constraints, but also by cost competition from other renewable energy sources, as discussed in Section 3.2.

### 3.2. Barriers to hydroelectric development

Barriers to hydroelectric (HE) development in NZ include physical, environmental and cost issues. In terms of physical factors, NZ hydro systems differ to most others in being low storage volume systems, with total storage being only some 34 days at peak winter demand [13]. The system is therefore prone to supply shortfalls in the event of variable inflows arising from annual or seasonal changes in precipitation or snow-melt. Within-year output variation around 20% was experienced during the 1990s [9]. Low inflow levels in 1989, 1992, 2003 and 2008 led to low dam levels and public campaigns to reduce consumption and, on occasion, actual supply reductions [13].

A second physical factor arises from the location of generation (typically remote) and consumption, with substantial transmission required including an undersea high voltage DC cable between the two islands. The eight 'short list' schemes identified by Ref. [14] are all in the South Island and hence would increase dependence on that critical infrastructure for delivery to consumers in the North Island, infrastructure which has had availability problems in the past [8,15].

Environmental considerations have been a major issue over the period of NZ's hydro development. Ref. [7] discussed the role played by hydroelectricity in NZ's development and described three major protest campaigns over proposed HE developments, all in the South Island. The first, Bowen Falls in the 1920s, was regarded as the first major conservation campaign in NZ; the second (Lake Manapouri 1960–72) as "the first great conservation success." The third concerned the proposed major scheme on the lower Waitaki river in 2001. Of the three schemes, only one was eventually built (Manapouri), and that scheme was significantly limited by the success of the campaign in preventing the raising of existing lake levels [7]. As noted in Section 3.1, most potential large river schemes in NZ are in declared conservation areas—and history would suggest that they would face major opposition in development.

The cost of HE output relative to other renewable sources, particularly wind and geothermal energy, is a further impediment to development. This is discussed further in Section 4.1.2 in considering the potential for wind energy development.

## 4. Wind power generation

New Zealand is a country well endowed with wind potential by virtue of its location and topography. It lies in the South Pacific between latitudes 34S and 47S, in the path of prevailing strong westerly winds—the "Roaring Forties", circumpolar winds traversing the Southern Ocean and driven by cold air from Antarctica. Wind energy is accessible through two regimes arising from the existence of central mountain ranges (particularly in the South Island), and a long coastline with many exposed sites influenced by sea breezes. High country site winds are generally more consistent than are coastal site winds, in both seasonal and diurnal terms [16].

The potential from this source attracted attention in the 1970s, with the establishment in 1974 of a Wind Energy Task Force which undertook extensive measurement and modeling through to 1980 [16]. Its work was, however, followed by a period of low international oil prices, and it was nearly twenty years before the first commercial wind turbine (of 226 kW) was commissioned in Wellington. The site was chosen as a test site because of its strong winds. The turbine concerned subsequently operated continuously for over 15 years before requiring repair [17–19]. It was to be a further ten years before significant further capacity was added, with development on a larger scale commencing from 2003. Wind power growth in NZ is shown in Fig. 2. Capacity is expected to reach 615 MW in 2011 with the completion of plant under construction.

A substantial number of projects are under current consideration, and they reflect both the potential for wind development, and the issues associated with the development of the industry. Plants of around 780 MW potential capacity exist for which regulatory approval ('resource consents') have been attained, and another project equivalent to total current installed capacity (Project Hayes, of 630 MW) is progressing through a contested regulatory approval process [17–19]. While clearly not all potential projects may be built, a significant increase in wind capacity in NZ appears likely over the next few years, subject to the barriers discussed in Section 4.1.

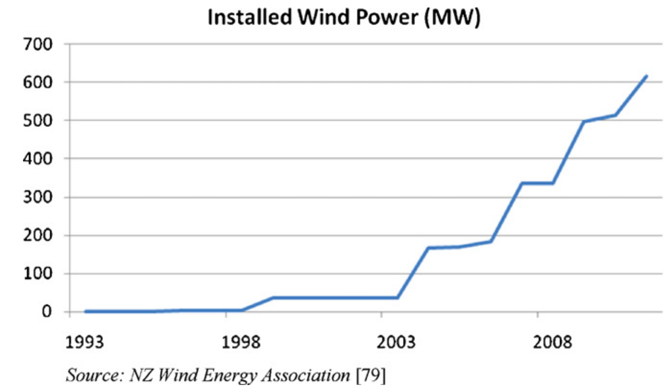



**Fig. 2.** Installed wind power capacity.

### 4.1. Potential wind capacity and utilisation

The variable nature of wind power generation implies particular limitations on its use. Not only must the capacity to generate exist, but also the systems into which variable amounts of power are being supplied must be capable of operating in a stable manner in meeting all applied demand load at essentially constant frequency. In NZ, that situation is complicated further by the fact that substantial power transmission takes place between the two islands, largely from the South Island to the North Island. The undersea transmission link is a direct current connection, and the systems on each island are frequency stabilised separately [20]. The fact that electricity demand and wind power input vary independently mean that at some times non-wind sources must increase to compensate for reduced wind input, and at other times those sources must be reduced. Failure to do so means that in the one situation power shortages (and hence frequency reduction) may occur; in the other direction wind power must be 'spilled' thus reducing the economics of wind generation. System integration is therefore a significant issue.

#### 4.1.1. System integration

A study carried out in 2005 sought to quantify the possible contribution of wind power to the NZ system using the operating data of 2005, and identifying the reserve (non-wind) capacity required to be available for system stability purposes. That suggested that the system might be capable of accommodating some 34% of peak generation level as operating wind plant capacity, contributing in turn around 20% of total generated power [20]. A later, more dynamic model study used actual half-hourly generation data for the years 2005, 2006 and 2007 to evaluate what would be required to operate a fully renewable energy based system incorporating hydro, wind, geothermal and biomass generation. In addition to the constraint of meeting imposed demand, the study incorporated hydro dam level limits, using four different power supply configurations. Results indicated that what had been a 32% contribution from fossil fuel generation over that period could be replaced with non-fossil sources, with wind power comprising 22–25% of installed capacity, and a capacity credit ranging from 47% to 105% [13]. (The capacity credit depicts the installed capacity of other generation which could be replaced by the wind generation capacity installed).

The potential thus appears to exist for a significant percentage of NZ generation capacity to be in the form of wind, from the perspective of system management. In turn, studies on the availability of wind generation suggested there are substantial resources available.

**Table 1**
Assessed NZ wind power potential.

| Tranche | Ave capacity factor (%) | Expected cost ($NZ/MWh) | Available resource (GWh) |
|---|---|---|---|
| 1 | 40 | 75–90 Typical 85 | 50,780 |
| 2 | 35 | 90–105 Typical 100 | 42,420 |
| 3 | 30 | 105–125 Typical 115 | 34,170 |

*Source*: Connell Wagner [64].

#### 4.1.2. Wind generation capacity

As noted in Section 4 the location and terrain in NZ favour wind generation, in particular leading to high turbine productivity relative to other countries. Capacity factors (average output divided by rated capacity) in good sites in NZ may reach 45%, comparing very favourably to the global average of 24%, and 16% in Germany, a country notable for its wind power growth [21]. As a result there are substantial opportunities for wind development.

Current generation planning is largely based around a 2008 study undertaken for the Electricity Commission, which identified potential wind power projects and classified them into three 'tranches' based on average wind speeds and turbine types—hence reflecting on the economics of each tranche. The three tranches, their average capacity factors, expected power cost (as break-even power costs) and available production are summarised in Table 1.

The available resource values may be compared with the total energy demand of 42,010 GWh experienced in 2009, and the demand growth of 12,530 GWh/a predicted over the twenty-five years to 2034. Wind power comprised only 3.5% of total supply in 2009 [67], but clearly has a significant role to play in future electricity supply. The fact that it does not play a larger role now suggests the existence of significant impediments to development.

### 4.2. Barriers to wind development

The principal barriers to further wind development in NZ are environmental/social and economic. Environmental and social concerns over wind farm development have led to much-contested applications for approval, with the approval process being long and expensive. One project (since completed) is reported as having experienced a two year approval process and additional costs of $NZ120 M [21]. Surveys of those opposing wind farms have indicated a variety of factors driving opposition, including most particularly aspects of landscape impact, the size of turbines, construction impacts and noise. While broad public perceptions are positive, specific developments in NZ have met controversy, and significant public objection [22]. All project proposals are managed in consent terms through the Resource Management Act (RMA), and in 2009 the Government implemented a range of amendments to that legislation designed to improve resource consent processes generally [23]. The effect of these amendments to date is not clear.

Economic issues relate to both relative power costs, and the investment process. In terms of cost, wind power must be competitive with other forms of renewable energy, and with non-renewable energy from fossil fuels. Planning studies have shown wind in NZ to be broadly competitive with other forms of renewable energy such as hydro and solar and quasi-renewable forms such as geothermal [24]. That then raises the issue of why wind power development in NZ has not been greater, in terms of phasing out fossil fuel based generation. Gas and coal based generation still comprised 27% of total in 2009 [67]. As part of its Kyoto Protocol commitment, NZ has a need for to reduce its $CO_2$ emissions, and the energy industry contributed some 11.4% to those emissions in 2007 [70]. While the consent process may have imposed difficulties, it is evident that other factors have played a part.

One may be the limited pool of investors, reflected in the fact that in 2009, 99% of all existing wind power capacity was owned by only three developers [21], all generator/retailers. NZ's electricity industry is marked by high vertical integration and concentration, five companies ("gentailers") having 91% of generation capacity and supplying 97% of total demand [25]. Failure of other investors to enter the industry may in turn be due to that concentration. NZ's electricity market has exhibited a high degree of volatility, making returns on investment more risky. Existing 'gentailers' are implicitly hedged against such volatility, but this is not the case for new entrants, thus creating a barrier to entry. Hedging contracts of this nature are also difficult to obtain [21].

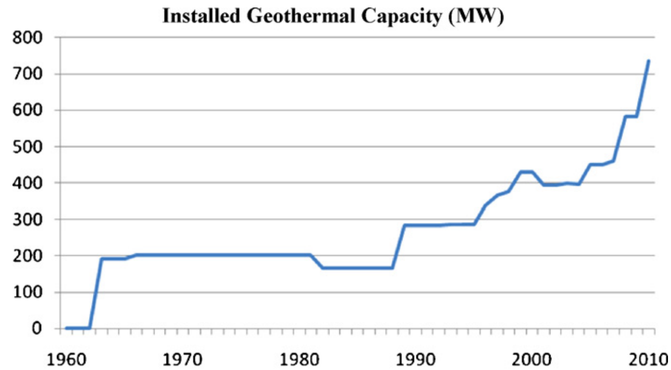
A second is the lack of policy instrument use by government to induce the required investment. The two main forms of such intervention elsewhere have been price-based and quantity-based systems, the former requiring power generators to be paid a specified price for their output, and the second requiring power purchasers to buy a certain quantity of the energy source in question. Price supports are commonly termed "feed-in" mechanisms, while quantity measures usually rely on certificate systems of some type. Generally, price-based systems have been notably more successful in inducing large scale wind development than have been quantity-based systems although, as with other policy instruments, specific aspects of instrument design strongly affect outcomes. In NZ, the only use of economic instruments prior to 2008 was the "Projects to Reduce Emissions" (PRE) scheme which operated until 2004 and involved participants tendering for government-provided 'emissions units' which could be traded internationally [26].

An emissions trading scheme has now been put in place which will ultimately allow renewable generators to gain tradable credits for their output [71]. As with the PRE scheme, returns to investors rely on the value of the emission credits which are created—and those values are not guaranteed. Such schemes are not generally used as the principal means to induce renewable energy investment [21]. In addition to having uncertain returns, trading schemes focus on emission reduction only and do not reward aspects such as improvement to overall supply security. If renewable energy is to be substantially developed in NZ, it is likely that more active policy instruments will be required.

One solution suggested to address a number of the impediments to wind power implies restructuring regulations to encourage small-scale wind projects. Such projects (typically involving three or fewer turbines) offer a number of advantages. First, their scale is such that they are likely to encounter less public resistance, and may well help acceptance of larger schemes also. Second, lower project costs make financing more accessible for individuals or small groups, and hence enlarge the potential investor pool. Third, their installation is likely to be more geographically dispersed, and hence improve both system security, and diversity of supply as compared to large wind farms whose overall output is affected by local wind conditions. While there are negatives through not achieving economies of scale, and grid connection costs, small scale wind development may offer a way to unlock much wind potential in NZ [21].

## 5. Geothermal energy

NZ owes its geothermal resources to its position at the south-west end of the so-called "Pacific Ring of Fire", where the Pacific and Australian tectonic plates collide [74]. Its geothermal resource exploitation is largely through geothermal waters [27] with some utilisation of direct steam. Geothermal energy is used for both power generation, and for direct thermal applications.




*Source: NZ Geothermal Association* [40]

**Fig. 3.** Installed geothermal capacity.

### 5.1. Geothermal electricity generation

As was the case with hydroelectricity, NZ was an early adopter of geothermal electricity generation also. Two years after the first geothermal electricity was demonstrated at Lardarello (in Italy) in 1904, the Spa Hotel in Taupo commenced generating geothermal electricity. It was, however, to be over fifty years before commercial scale production took place in NZ, in 1958 at Wairakei, the world's second commercial geothermal generation plant [28,63]. It was some thirty years before further capacity addition took place, total installed capacity reaching a little over 700 MW by 2010 (see Fig. 3).

Further capacity (including certain replacement for the Wairakei plant) is under construction, to provide a nett 65 MW increase in output, while projects for a further 430 MW of new capacity are also at various stages of seeking consent and financing [29].

#### 5.1.1. Potential geothermal generation

Capacity and cost studies suggest that geothermal generation is likely to be one of the lowest cost supply alternatives for some years. Most resources for this are in the Taupo volcanic zone, in the central North Island [24]. Assessments have suggested an available resource (on a median estimate) equivalent to some 3600 MW capacity. After allowance for prior extraction from fields, and likely environmental difficulties, a nett increment of 1100 MW was suggested as being available [30]. A more recent estimate suggests a likely increase to 1500 MW total by 2025, an increment of around 770 MW—a doubling of today's capacity [24].

Available capacity is likely to be supported in part by the greater use of binary cycles—using a low boiling point fluid in a secondary cycle to take advantage of lower temperatures than might be required for 'standard' flash steam power generation cycles. A number of these are already in operation, although several of the plants concerned still use high temperature geothermal sources. While binary cycle plants are typically smaller scale and higher cost, their ability to operate using lower temperature geothermal sources broadens the available resource base for generation overall, and improves recovery [69].

### 5.2. Direct thermal use of geothermal energy

Long before European arrival in NZ geothermal energy had been used by Maori for cooking, bathing and other purposes. Later uses included heating and bathing, and as the focus for major tourist attractions in the form of geysers, hot pools and other features [31,32]. Current direct use of geothermal heat occurs in a multitude of applications ranging from thermoculture and bathing (using temperatures less than 70 °C) to process heating using steam at up to 220 °C. Applications include water and space heating, horticulture, a prawn farm, timber drying, and process heat generally. Many of the uses are such that metering is not economic or practical, and hence usage data is limited. A 2006 estimate indicated that the contribution from direct geothermal use (at 9.5 PJ/year) was of the same order as the delivered electrical energy from geothermal generation (although with low generation cycle efficiencies, the primary energy input to generation was markedly higher). Around 55% of that energy is consumed in one major industrial location, a pulp and paper operation at Kawerau, one of the largest geothermal energy consumers in the world [33]. The geothermal source is fully integrated into the plant's energy system [34].

In terms of development potential, significant though unquantified capacity is considered to exist for direct geothermal energy use, both for further process and space heating purposes directly, and through applications such as ground source heat pumps for domestic and commercial applications [69]. Outside the Taupo volcanic zone, lower temperature groundwater resources exist both in the northern North Island, and in a band following a longitudinal fault line in the South Island [27]. In many cases, however, utilisation may be limited by the distance of potential users from the available resource.

### 5.3. Barriers to geothermal development

While capacity exists for further development of geothermal resources, there are environmental and other issues which may work to limit the rate or scope of development. The nature of potential environmental problems is well illustrated by the results of over-development which occurred in the Rotorua area over the decades up to the mid 1980s. With essentially unregulated development, extraction from geothermal fields was such as to lead to the extinction of major geysers and drying up of hot springs. Land subsidence of up to 10 m was recorded, the highest ever recorded for subsidence due to underground fluid withdrawal. With major tourist attractions threatened, the government ultimately assumed planning control for the area, and instituted a program of forced geothermal well closures, together with charges for fluid withdrawal. There were in 1986 900 wells operating in Rotorua, withdrawing 32,000 tonnes/day in winter [35]. Only some 5% of extracted fluid was reinjected. Following well closures, and the introduction of royalty charges and reinjection credits, total well discharge was reduced by more than two thirds, with nett fluid withdrawal reducing to 11,300 tonnes/day.

Despite this major step, while some recovery of geothermal features took place, many major features including a number of significant geysers did not recover. The effects of uncontrolled geothermal development were accompanied also by the effects of several hydroelectric developments in the same area, which had led to the quenching of geysers, and the flooding of hot springs. One episode, at Orakeikorako, was remembered as "one of the greatest environmental losses in the history of New Zealand."

Losses associated with such events are not solely in the intrinsic or existence value of the environmental features concerned. The geothermal environment is a major resource for 'biological prospecting' involving such elements as thermophilic bacteria. On a more visible scale, the geothermal features of the areas concerned are a significant factor in tourism, a 2000 estimate suggesting that the geothermal features contributed some $NZ310 M per year to NZ tourism [35]. This may be compared to a 2009 estimate of the total value of electricity generated geothermally in NZ, at $NZ350 M [69]. Clearly geothermal development which impacts negatively on tourism has the potential to cause nett economic loss.

The Waikato Regional Council, the authority administering the Resource Management Act for the major part of the high-

temperature geothermal region, has adopted a classification system for potential sites which has regard to likely damage to surface features, and regulates development appropriately. The geothermal industry body, while supporting the RMA, has suggested that such classification limits geothermal development potential [31,32].

A second issue concerns the resolution of claims to ownership of geothermal resources by Maori, with those issues being progressively resolved. Geothermal features are accorded cultural significance by Maori, who espouse a role as guardians of the resource for the future. Maori groups have been involved actively in geothermal project development projects where appropriate [36].

### 5.4. Renewable energy and geothermal development

Geothermal energy is often classified as "renewable energy", as for example in NZ Government reports (see for example Ref. [67]), presumably to differentiate it from the visibly non-renewable forms such as oil, gas or coal. NZ legislation in fact recognises geothermal energy as 'renewable' for the purposes of the Resource Management Act [29]. Accessible geothermal energy is found where heat from the decay of radioactive elements in the earth's core makes its way through favourable geological structures, in a relatively concentrated form, to the earth's surface. A heat carrier fluid such as water then allows that heat to be 'harvested' for generation and direct energy purposes. As with any other process, the process is sustainable where the rate of withdrawal of energy is at a rate lower than the rate of energy supply. Where extraction rates exceed that threshold, then the capacity of the geothermal resource itself will decline. If extraction ceases, then the resource may 'recharge' itself. A simulation study of the Wairakei geothermal field for example suggested that the field would be likely to be effectively exhausted in resource terms after roughly one hundred years of production at current rates. If the field were then shut down, the system would return to its original state after some 400 years [37].

To that extent the system is renewable in principle, if not in the concept to which the term renewability is more commonly applied. To meet that criterion, energy extraction would need to be limited to the rate at which heat was rising to the surface. Whether geothermal development is economic at that level would depend on the circumstances of the particular project. Here, geothermal energy has been assessed with more literally renewable energy forms, given that the focus here is on energy forms with low emission consequences—and in that sense, geothermal sources are clearly more akin to renewable energy forms than to fossil fuels.

## 6. Solar energy

New Zealand's location and topography are less favourable to solar energy utilisation than to wind and marine power. A substantial potential does, however, exist. Indicative insolation levels in the three major population areas for example (with nearly 60% of the total population [4]) range from 1300 to 1580 kWh/m$^2$/year [38]. Average levels in Germany, a country notable for its level of solar development, range from 950 to 1100 kWh/m$^2$/year [39]—suggesting that solar utilisation in NZ is not limited by the available source energy. The greater constraint in this instance is economic.

### 6.1. Solar hot water systems

The two principal solar applications in NZ have been in hot water systems (HWS), primarily at the domestic level, and a much smaller use of photovoltaic (PV) power generation systems. Large scale solar power generation is considered unlikely to be economic in NZ, given 'fickle' weather conditions [40]. Hence hot water systems have been the principal object of policy measures to date. Nearly 30% of total domestic energy consumption goes to water heating, with electricity supplying 75% of total energy, gas 20% and solid fuels 5% [41]. Adoption of solar HWS therefore principally reduces electricity use. The approach to promoting solar HWS has rested to date on modest subsidy schemes.

Market penetration of solar HWS has been slow relative to other countries. By 2007, around 34,000 systems had been installed, for a total of 0.81 systems per 100 people, around one tenth that of Germany. The first incentive scheme was introduced in 1978 with the availability of an interest free loan of $500 towards system installation. The scheme was not notably successful and was replaced by a $300 subsidy scheme in 2002, the subsidy later in 2006 increasing to $500, but with performance qualifications. System performance and installation quality were problem issues in the early phases [42]. Based on typical total system costs of $NZ4000 to $NZ7000 the payback period for solar HWS was typically five to six years [43]. In 2010, the system was amended again, to provide subsidies of either $NZ500 or $1000 depending on the level of energy savings [65,66]. Results from the amended scheme are not yet available, but it is apparent that there exists a substantial potential to deploy the technology, depending on the effectiveness of the policy instruments applied.

### 6.2. Solar power generation

The power generation (PV) systems market has developed only slowly in NZ, supported largely by off-grid (stand alone) systems to date. In terms of other applications, a 2009 study analysed the likely cost trajectory of PV systems against expected future electricity prices in NZ [44]. Indications were that large scale ('solar farm') installations were unlikely to be economic in the period to 2035; that commercial and light industrial applications might become economic by 2020; and that domestic PV installations would also become economic in their own right around 2020, with likely major growth from that time.

To date the only substantive support given solar in NZ has been the relatively modest support given HWS systems, and industry development and market penetration are consistent with that. That lack of support must be seen as in part reflecting already high levels of renewable energy application in NZ, such that the emission gains from electricity replacement are smaller than elsewhere. It is also reflective of the relatively market-oriented views of successive governments, within which market incentives for RE development purposes do not sit well. While that remains the case the application of solar energy is likely to remain constrained.

## 7. Marine energy

As with wind power, NZ enjoys a substantial potential for wave power development through its exposure to Southern Ocean winds and the waves generated by them, impacting on the western and southern coasts of the North and South Islands [45]. Unlike wind power however, the industry is still at a nascent stage, mirroring (and lagging somewhat behind) marine energy developments worldwide. Internationally, while there is recognised a large potential resource for both wave and tidal power, development has also been relatively slow, and most commonly dependent on government subsidy for the actual implementation of the technologies concerned.

Worldwide there are no installations of substantive capacity in wave power, and in tidal power the only major installations are a tidal barrage system near St Malo, France, employing twenty four 10MW turbines and operating for some 37 years, and a 20 MW

station at Annapolis Royal, Canada, installed in 1984 [46]. Various other tidal stream devices are at differing stages of development, such as the Atlantis Resources 1MW turbine unit (thought to be the largest of its type) being installed at a test centre in the Orkney Islands in 2010 [47].

To date the only commercial project in NZ has been one in the remote Chatham Islands, where government funding has assisted the installation of two 110 kW turbines to replace diesel generator output and due for commissioning in 2012 [48]. There has, however, been broad investigation activity, local device development (a wave power device) and consents sought and gained for trial installations [49].

### 7.1. Marine energy potential

The most comprehensive assessment of marine power capacity in NZ was that undertaken by consultants Power Projects for the Electricity Commission in 2008. That study reviewed several previous 'broad brush' studies, and extended those by combining models of available wave and tidal energy at different sites, and models of device performance to produce estimates of recoverable power. Their conclusion was that there was a potential wave power in excess of 7000 MW available, and a potential tidal power between 500 and 1000 MW. They noted, however, that these estimates "should be treated with great caution" and that broadly it could only be assumed that the available wave and tidal potential exceeded the likely demand for those sources in NZ—provided marine power costs could be reduced sufficiently to make them competitive with other sources of renewable energy. Other sources of marine energy (such as marine biomass, and thermal energy) were not considered to be adequately served in terms of available conversion processes to be considered at this time [49].

It is considered therefore that marine power (other than niche applications such as the Chathams project noted above) is unlikely to see near-term large scale development in NZ of the scale envisaged, for example, for wind power.

## 8. Biomass

The worldwide application of biomass based renewable energy has been developing rapidly, in part because of its potential to address four common policy objectives—carbon emission reduction, energy security, regional employment, and environmental improvement [50]. Biofuels for example are identified in the low (or negative) cost portion of the global emissions abatement supply curve depicting available abatement measures for 2030 [51]. In 1999, woodfuel use worldwide was around 2.3 billion $m^3$/year, and the largest renewable energy source [52]. NZ as a country with quality arable land and favourable climate has in principle a major biomass potential. The issue for biomass development in NZ is not, however, the primary resource availability but rather quite complex issues of opportunity cost.

'Biomass' in NZ essentially arises from two sources—purpose-grown biomass ((including energy crops, woody biomass including trees, and algae), and residues generated in industries employing biomass, largely the timber industry, and pulp and paper industry. In the latter residues arise both in the felling of timber, and from the subsequent processing of that timber [28]. It is already used on a significant scale for both direct thermal purposes, and cogeneration. Woody biomass made up over 18% of total renewable energy in NZ in 2009, and 6.5% of total primary energy supply. The principal uses were direct use industrial heating, industrial cogeneration (particularly in the timber and paper industries) and domestic heating. Total direct or indirect biomass use in NZ for thermal purposes in 2009 included 42.9 PJ for industrial use and 7.6 PJ for residential use [67], the latter supplying 38% of total domestic space heating. Domestic use is expected to grow with the wider application of wood pellet burning appliances as a more efficient and convenient method of household heating [28]. The total of 50.5 PJ used in 2009 equates to around 2.5 million tonnes of biomass [53].

The use of biofuels in NZ is at a much less developed stage. Biodiesel is produced, primarily from tallow, with some makeup from used vegetable oils. Quantities are not large, output in 2006 being some 5 million l [54]. If total NZ tallow production of 150,000 tonnes/year were to be devoted to biodiesel, it could supply only some 5% of total diesel fuel consumption [55]. Ethanol is also produced from a dairy byproduct, but only a small amount goes to use as a petrol supplement, any other ethanol being imported [54]. Further development of biofuels will depend on the opportunity cost of the available biomass feedstock.

### 8.1. Development potential, resources and opportunity cost

NZ is a country in which agriculture and forestry are significant industries. Agriculture accounts for some 4.5% of GDP, but is of considerably greater importance to trade. Direct food and live animal exports comprised around half of New Zealand's export trade in 2008 [56,57]. It is the world's largest producer of traded dairy products. One firm, Fonterra, is the world's largest exporter of dairy products [58]. That export contribution is important for a country such as NZ which incurs a persistent current account deficit, reaching nearly 9% of GDP in 2006 [56,57]. Hence industries which depend on feedstocks also needed by agriculture and export forestry pose major policy and opportunity cost issues. The issue of land resource competition, most commonly between crops for biofuels, and food crops, is also a matter of concern in a number of developing countries.

Increasing the resource base needed for either biomass thermal energy, or biofuels, depend in large part on accessing resources already in use by other industries. To grow energy crops implies diversion of cropping capacity from other agricultural or forestry uses. As such, the economics of biomass utilisation are intrinsically tied to international prices in otherwise unrelated markets. The one exception of any substance lies in biomass materials not currently utilised—residues arising from the felling and removal of trees. Residues arising from the further processing of timber in mills are commonly recycled for thermal use, often driven by the alternative cost of disposal.

On-site residues from felling trees range from 4% to 6% of the volume of timber extracted. That suggests a residue volume generated of around 1 million $m^3$ in 2006 [53]—but a residue volume which is distributed widely over all areas of active logging. A study undertaken in 2008 on a residue-based biofuel (ethanol) plant illustrated several of the issues constraining further biomass development. The study considered a plant size of 150 million l per year—only around half the size of a typical US maize-based ethanol plant. That plant, however, would have consumed the equivalent of all available forestry residues in the North Island. Because of the distributed nature of the feedstock resource, residue transport costs dictated that feedstock in part be funded by logs that would otherwise go to pulp production [59]. The assessment illustrated well the limitation of biomass resources not already committed to other products, and the dependence of biofuel production on prices in other unrelated markets. In a second example, wood which is directed to wood pellets for thermal use may realise a value of $NZ300/tonne as pellets—or go as a pulp towards fibre board at a product value of $NZ1500/tonne, or towards white paper at a product value of $NZ2000/tonne, depending on quality [53].

A second determinant of biomass development potential is government policy. Biomass energy has been impacted by three policy measures. The first (the "Projects to Reduce Emissions" program)

involved firms seeking support for projects which would reduce greenhouse emissions, and who tendered in 2003 and 2004 for government support. Successful tenderers were awarded tradable emissions units as a form of subsidy. In that program, six biomass projects were successful in tendering, but only two (relatively small) projects were still extant by 2009 [72]. A second initiative sought to target incentives directly at biofuels, by introducing a compulsory consumption target (the "Biofuels Obligation"). This was introduced in September 2008, only to be repealed after a change in government, in December 2008 [60]. It was replaced in 2009 with a direct subsidy on biofuel sales, which was of limited success and was amended in 2010 [61,62]. The third measure was an emissions trading scheme introduced in 2008 and amended in 2009. Under those amendments the stationary energy, industrial processes and liquid fossil fuels sectors were to participate in the scheme from July 2009 [71].

At this time it is not clear to what extent the ETS will promote biomass as a means of emission reduction. While the ETS may have the effect of improving the economics of biomass utilisation, it will do so for all renewables. In addition, the very real cost barriers to biomass development arising from other higher value uses for the biomass feedstock will remain.

## 9. Summary and conclusion

New Zealand is a country which for its size has an unusually broad endowment of potential renewable energy resources. Some of these have been exploited for many years, as shown for example in the portion of electricity, 60%, generated from renewable resources. In more recent years, however, RE development has been less than that in many other countries, due to barriers some of which are specific to certain forms of RE, and some which are general. In the case of hydro, geothermal and wind, environmental and resource consent issues are significant factors in development. In the case of biomass and related biofuels, competition for growing capacity with other products, including those particularly which are export related, is real, and likely to be a major determinant of development. In the case of geothermal energy, conflict is possible between the further development of power generation, and current and future tourism potential. In both cases, the issue of true sustainability is central to resolving the competing resource demands.

Issues of industry concentration may well be a factor inhibiting market entry in the case of wind power generation. Overall, policy incentives are less than in other countries such as Germany and the US which have adopted a more proactive RE development policy stance. The lack of concrete and 'bankable' incentives has the potential to not only limit development overall, but also limit the extent to which industry development may be approached from a strategic perspective.

An ambitious target of producing 90% of electricity generation from renewable sources (including, for the purposes here, geothermal energy) has been adopted. Economic studies suggest the most likely candidates to support that target are wind and geothermal energy. The achievement of that RE target will depend to a large extent on the effectiveness with which government policy is developed, clearly enunciated and applied—policy in relation to competing resource demands, policy in regards to barriers to development, and policies in terms of RE development overall. That of itself presents a challenging task for government in managing New Zealand's renewable energy development.

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